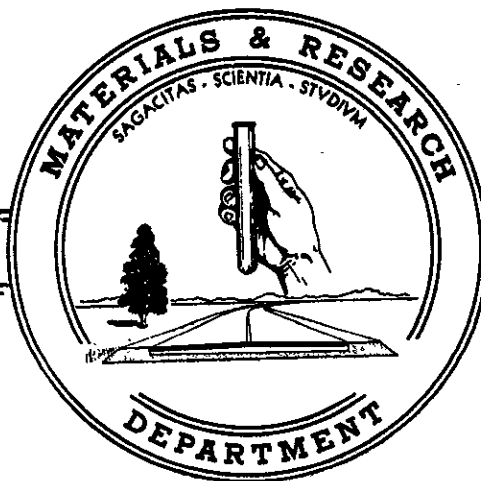**STATE OF CALIFORNIA**
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

A PROGRESS REPORT ON

THE STUDY OF CULVERT DETERIORATION

March 1960

60-10

State of California
Department of Public Works
Division of Highways
Materials and Research Department

March 1960

Mr. J. C. Womack
State Highway Engineer
Division of Highways
1120 N Street
Sacramento 14, California

Dear Sir:

Submitted for your consideration is:

A PROGRESS REPORT ON

THE STUDY OF CULVERT DETERIORATION

A Method for Estimating the
Life of Metal Culverts and
Other Underground Structures
and Tentative Control Tests
for the Use of Concrete Pipe

Study made by . . . . Structural Materials Section
Under general direction of . . . . J. L. Beaton
Concrete advisor . . . . Bailey Tremper
Work supervised and report prepared by . . . . R. F. Stratfull

Very truly yours,

F. N. Hveem
Materials and Research Engineer

RFS:mw
cc: Hdqtrs. Departments

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I. INTRODUCTION

At present there are no objective means for completely evaluating a proposed culvert site insofar as the site may affect the service life of culvert material.

Since the replacement of a culvert can be expensive and also can seriously disrupt traffic service, it is important that the designer have as much pertinent preliminary information as can be obtained within limits of reasonable cost and time. At present fairly adequate hydraulic and foundation data can be obtained; however, knowledge concerning the effect of environmental components on the life of culvert material is not comprehensive.

This report outlines a new preliminary survey procedure that has been found to correlate well with existing highway culvert performance on a state-wide basis.

In January 1952 the Materials and Research Department was assigned the problem of investigating and evaluating the condition of corrugated metal culverts in District I. Specifically, the scope and aims of the study may be subdivided as follows: (1) determining whether or not certain environmental conditions tend to accelerate the corrosion rate of metal culvert pipes, (2) preparing a map of District I to indicate the areas or sections of highways where the average corrosion of culverts is marked, moderate or minor, (3) developing practical means to identify potentially corrosive areas as a guide for new construction in any area, and (4) recommending steps to repair or prevent failure in deteriorated installations.

Due to the scope of this assignment, it was decided to program the study into several parts. The first phase, covered in a report dated May 10, 1954, also included one method for repairing deteriorated culverts, namely the process of applying a mortar lining by the Centriline process. As a trial installation 8 culverts in District I on Routes 48 and 56 were lined. An additional report, dated March 1, 1955, covered portions of items (1) and (2), and those parts of (3) and (4) that were not separable from the first.

In general the following discussion relates to the 3rd item which is the development of practical means to identify potentially corrosive areas by site investigation and laboratory test methods.

II. SUMMARY AND CONCLUSIONS

The life of metal culverts is a variable depending upon the environment. The significant environmental factors include the watershed soils, vegetation, rainfall, flow, backfill material, etc.

There are inter-relationships between the factors as certain important details of the environment, i.e.: vegetation, soil pH, and resistivity are often markedly influenced by the annual rainfall. High annual rainfall in an area normally insures that the watershed soil will contain few soluble salts and will have a low pH.

The combined influence of the measured pH and the electrical resistivity of the soil has been mathematically related to the corrosion life of metal culverts. The combined effect of the pH and electrical resistivity of the soil appears to exert greater influence on the corrosion rate of culverts than does the amount of rainfall alone.

A method has been developed for predicting the life of metal culverts from laboratory test data on resistivity and pH of soils (see Exhibit I). Statistical analysis indicates, however, that the over-all accuracy (standard deviation) of the method is not closer than plus or minus 12 years. Therefore, when possible, existing culverts should be inspected as a check on the estimate.

The chart (Figure I) is based on the use of plain galvanized culvert metal. If the pipe is to be bituminous coated, this is an additional factor which should be considered in predicting service life.

It was found that the state-wide average increase in the life of galvanized metal culverts was approximately 6 years when the pipe was coated with asphalt[1]. However, the evidence of increase in the average service life of culverts with a bituminous coating should not be thought of as always a completely dependable benefit when considering the economic design of specific installations. The additional life afforded by the plain asphalt coating on culverts could be insignificant in areas of high rainfall and abrasion, but economically well worthwhile in areas of low rainfall. The actual economic value of pipe coatings at specific locations depends upon the local environment and may not correspond to the state-wide average.

[1]Note: The asphalt coating referred to in this study was in place on old existing pipes and was an uncontrolled commercial type of dip. The presently specified bituminous dip and lining material is superior to the old and should result in a greater increase in life than indicated by this report.

Our efforts in trying to establish relationships between measurable factors and the life of the metal culverts led to study of other work done in this field. The National Bureau of Standards has carried on nationwide studies of underground corrosion conditions and has developed the Denison Corrosion Cell Test. We recognize that this is probably the most accurate method available for predicting underground corrosion rates. However, the test requires a six months' period for completion. The method proposed in this report for estimating the corrosion rate of buried steel by determining the pH values and the resistivity of the soil is considered to be sufficiently accurate for practical design purposes. If greater accuracy is warranted and if ample time for testing is available, the Denison Electrolytic Corrosion Cell Test could be utilized.

III. RECOMMENDATIONS

A. Where considered economical, a corrosion survey should be made of each proposed culvert site to obtain the following information:

    1. Watershed soil resistivity and pH.

    2. pH of the watershed water and resistivity at low flow.

    3. Proposed backfill soil resistivity and pH.

    4. History and present condition of existing culverts, if any.

    5. Soluble sulphate content of both backfill and watershed soil or waters. Such information to be obtained only when sample measures less than 3000 ohm/cm^3 resistivity.

B. Utilizing the above information and the following procedure, determine the serviceability of the structure.

    1. Metal Culverts

        a. Obtain the anticipated life of the pipe from the chart, Exhibit I.

        b. With the exception of locations of virtually continuous flow, consider that a bituminous coating may add 6 years to the life of a metal pipe so far as the corrosive effect of the flow is concerned.

        c. In areas of nearly or fully continuous flow, the pipe should be asphalt dipped and the invert paved. It should be considered that this may add 20 years to the life of the pipe.

        d. In areas where the corrosion is known to be from the soil backfill, then a bituminous coating may be considered adding 25 years to life of a metal pipe.

    2. Concrete Culverts

        a. In sites detrimental to concrete, assume concrete to have at least a 50 year life in any location when modified as given below.

        b. All concrete culverts (except underdrains) subject to flow of water with a pH of 5.5

or less should be protected by an acid resistant lining (or invert lining only, if appropriate). Concrete pipe should not be used as underdrains in any location subject to water having a pH of 6.5 or less when the wall thickness is less than one inch. This limit also applies to porous concrete pipe of any shell thickness.

c. Concrete culverts placed in sea water should have additional protection of the reinforcing steel over that normally provided. This may be accomplished by an additional one inch cover of concrete and/or by requiring centrifugal spun pipe using a mix designed for maximum density or by increasing the cement content.

d. In areas of high sulphate content, Type V cement or other protective measures may be necessary. A special materials study should be made before using Type V cement.

3. Field Survey

a. The corrosion survey should follow the procedure outlined in Section IV, Field Survey Procedure, of this report.

IV. FIELD SURVEY PROCEDURE

1. In the procedure established in this Department, the natural soil in each channel or culvert location and the structural backfill material are tested by a portable earth resistivity meter. The resistivity of the soil in the field is measured by saturating the soil in the probe hole with approximately 2 oz. of distilled water.

2. The soils selected for laboratory analysis should be those that deviate by a significant difference from the average earth resistivity value. The criterion for a significant difference in earth resistivity is governed by the life of 16 gage metal culvert as shown on Exhibit I and also whether the highway is considered to be on "permanent" alignment. Otherwise, a minimum of three samples from each project should be obtained for laboratory analysis.

3. If the minimum resistance of a soil is determined to be less than 3000 ohm/cm^3 in the laboratory, at least 30 pounds of the soil should be obtained for a soluble solids analysis.

4. A portable pH meter is utilized to measure the pH of the waters in the field. pH readings may be taken at any period other than flood flow.

5. All waters which have a measured pH less than 6 should be sampled for further chemical analysis in one quart bottles.

V. THE LIFE OF METAL CULVERTS

As stated in the Summary, the life of a metal culvert is a variable depending upon the environment. Therefore, given a sufficient number of culverts, it should be possible to establish a statistical relationship between the factors comprising the environment and the resulting rates of corrosion. For instance, in the Materials and Research Department report of 1925, by Mr. McKesson and Mr. Stonebraker, it was observed that the rate of culvert corrosion increased as the average rainfall increased. The authors concluded that the average life of metal culverts in California is 80 years. Also, it appeared that when the rainfall increased from 10 to 80 inches per year, the average life of the culverts was reduced by 1/3.

In the Materials and Research Department's report on the condition of the corrugated metal culverts in District I, dated March 1, 1955, it was stated that the life ranges of corrugated metal culverts could be reasonably grouped in geographic areas according to relative corrosion rates. However, the average life of culverts could vary among the "Corrosion Area" groupings by 20 to 60 years. Therefore, it is apparent that figures purporting to show the average life of metal culverts are not very useful to a designer dealing with individual installations unless the figures are representative of the geographic area under consideration.

VI. ESTIMATING THE LIFE OF METAL CULVERTS

Four variables were considered as possible indices to the probable life of metal culverts. These variables were: average annual rainfall, pH, electrical resistivity of the soil, and the evidence furnished by the performance of the existing culverts.

A linear equation was developed by the method of least squares showing the influence of the three considered environmental variables on the performance of metal culverts. The computed correlation coefficient was 0.219, which was indicative of a real correlation at the 5% level of significance. However, when the statistical equation for correlating the life of metal culverts to environment was checked by computing the actual data in the theoretical equation, it was apparent that the relationships among the four variables were not linear nor accurately expressed by the equation, except at the mean values.

Therefore, the data were arranged into graphs on which culvert life is plotted against rainfall, resistivity, and pH, and these environmental factors were plotted against one another in order to examine a number of different relationships by trial and error. (See Sections VIII, IX, X, and XI of this report.)

Exhibit I represents a graphical solution of the data for predicting the rate of corrosion of metal culverts. For the present, it is considered that there is a linear relationship between service life and thickness of metal. For instance, it is assumed that in the same environment a metal culvert of 7 gage thickness will last about 3 times longer than a culvert of 16 gage thickness. In Exhibit I the chart is expressed in years to perforation of 16 gage culverts. Since the greatest percentage of metal pipes utilized for drainage structures have a metal thickness of 16 gage, it was apparent that numerous calculations would be eliminated if the chart values were expressed directly for this gage of metal rather than in ounces per square foot per year. It should be understood that the estimated years-to-perforation of a metal culvert does not necessarily mean that the culvert will collapse or that its usefulness as a carrier of water will cease. Instead this period of years-to-perforation is considered as a common yardstick for all culverts. If it is considered that the arching action of a fill is sufficiently substantial to warrant disregard of a perforation or loss of the culvert invert, then the arching action of the fill should be considered in the mechanics of the design.

The degree of correlation between the mathematically computed theoretical life from Exhibit I compared to the actual life of metal culverts as found in the field was computed by the method of least squares. It was found that there was a correlation coefficient of 0.344 which is indicative of about 0.08% level of significance. The standard deviation of the theoretical life

for culverts was found to be within 12 years of the actual service life. As the total investigation included culverts that were asphalt coated for corrosion protection, only those culverts without the asphalt coatings were analyzed in the original calculations.

After Exhibit I was prepared, the theoretical life of plain galvanized culverts and the estimated service life for asphalt coated pipes in the same locations was statistically analyzed by the method of least squares to determine whether the life attributed to asphalt coated pipes would affect the theoretical value. The results of the statistical analysis for the 68 asphalt coated pipes resulted in a correlation coefficient of 0.324 which is indicative of about 0.08% level of significance. The standard deviation of the theoretical from the actual data was found to be within 14.5 years. This analysis indicated a greater standard deviation between the theoretical and the actual life of asphalt dipped culverts than found in galvanized culverts. It appeared that the asphalt coating influenced the life of culverts.

Since the average life of the plain galvanized culverts in this study was found to be about 6 years less than the life of the asphalt coated pipes, it was decided to statistically determine whether the average difference in life as indicated by the two sets of calculations could be the result of chance.

That there was an actual difference in the average life of the coated and uncoated pipes was demonstrated at the 2% significance level using the statistical "t" test.

Since this significance level indicated that the difference in life between coated and uncoated pipe was not likely to be due to a chance sampling, it appears that the over-all state-wide gain in service life of galvanized pipe due to the asphalt coating is about 6 years. This difference in the service life is significant, but it should not be assumed that the service life of all pipes will be extended 6 years by an asphalt coating. For instance, it has been observed that in the desert areas where the corrosion attack is primarily on the soil side of the culvert, the service life could be increased 25 or more years by an asphalt coating. However, it is also obvious that in areas where the corrosion attack is predominantly from the flow of water, the increase in the uncoated service life can be less as the coating could be abraded from the culvert invert during a single winter.

VII. METHOD USED TO EVALUATE THE CONDITION

OF CULVERTS

The detailed method used during this study for inspection and rating culverts was described in our report to Mr. G. T. McCoy, State Highway Engineer, titled "The Report of a Survey of the Condition of the Corrugated Metal Culverts in District I", dated March 1, 1955. Essentially the described method is to strike the metal culvert with a geologist's pick and estimate the metal loss by the penetration or rebound of the pick. Although the method is far from precise, an estimate of metal losses can be made quickly with a fair degree of reproducibility.

While there are inaccuracies in this method for determining the metal loss of a culvert, the corrosion rate of a metal culvert can fluctuate even more than the variations in evaluation due to the testing method.

In other words the method of evaluation is well within the range of variation that is normally displayed by the culverts.

VIII. RAINFALL AND ITS EFFECT ON THE CORROSION RATE

As previously discussed, it was reported in the 1925 investigation by the Materials and Research Department that apparently the corrosion rate of culverts increased as the average annual rainfall increased. One of the first steps in this most recent analysis was to examine the new data to determine whether the corrosion rate of culverts accumulated in this study did consistently increase with an increase in the annual rainfall.

Exhibit II shows a plot of the annual rainfall in certain areas against the estimated life of metal culverts in the area. This graph indicates that as the annual rainfall increases so does the apparent life of the metal culverts. This is not in accord with the conclusions reached from the work of 1925 and 1955, which seemed to indicate that the corrosion rate increased with annual rainfall.

The 1955 study of District I showed that in the northwestern part of the State, the corrosion rate was influenced by the presence of anaerobic bacteria and vegetation. The presumed presence of anaerobic bacteria (perhaps Sporovibrio desulfuricans) was indicated when there was ponded water or continuous flow which caused moist soil conditions to prevail. These environmental conditions are predominantly associated with areas of high rainfall; areas of low annual rainfall such as the arid desert regions are not conducive to the propagation of such organisms. Therefore, the plot of rainfall against culvert life shown on Exhibit II indicates that the average annual rainfall per se may not be the direct cause of variations in the corrosion rate. However, the rainfall may contribute to the development of other conditions which in turn do influence the corrosion rate directly.

Since the plot of the service life of metal pipe does not confirm the earlier idea that there will be a decrease in culvert life with an increase in average annual rainfall, it is obvious that the reliance on a single factor for estimating culvert life is hazardous. The data in this report shows that as the average annual rainfall increases, the pH of the soil tends to become lower, indicating an increased acidity. It is well known that other factors being equal, the corrosion rate of steel is greater in an acid than in an alkaline medium.

There were insufficient samples obtained in this study to eliminate the effects of pH and salts when the life of metal culverts was compared to the average annual rainfall. However, it is clear that when the data were analyzed for specific characteristics, such as pH and the electrical resistivity of the soils, these properties were related to rainfall.

Therefore, we conclude that the rainfall or lack of it establishes conditions that in turn affect corrosion rates directly.

IX.   pH OF THE SOIL AND CORROSION RATES

In this study approximately 200 soil samples were chemically analyzed for characteristics which might be related to the corrosive characteristics of soils. One of the more simple tests that indicate significant properties of a soil is determination of the hydrogen-ion concentration, or pH. A pH of less than 7 indicates an acidic condition, pH 7 indicates neutral, and a pH greater than 7 indicates a basic or alkaline condition. Generally it is considered that acidic solutions attack steel at a more rapid rate than does an alkaline solution.

Shown on Exhibit II is a plot of the state-wide soil pH against the estimated life of metal culverts. In this plot as well as in the plot of rainfall against life, it appears that the apparent correlations are in reverse. The trend of data in Exhibit II indicates that as the pH reduces from a high degree of alkalinity to the neutral point, the life of the metal pipe increases.

Since the relationship of pH and also rainfall to corrosion rates apparently did not conform to accepted theories of corrosion, these factors were analyzed to determine whether this apparent lack of correlation was due to sampling methods or to other causes.

When the average annual rainfall was plotted against the pH of the soils, it was observed (Exhibit III) that as the average rainfall increased, the pH of the soil tends to be lower (acidic). The geographic areas of low rainfall are located in the desert areas with soil pH being in the alkaline range. The geographic areas of high rainfall are the mountainous regions with soils in the acidic range of pH. Apparently a high annual rainfall tends to leach out the soluble salts, and the decay of vegetation may contribute to the phenomenon of low soil pH with high rainfall. It appears that annual rainfall affects the corrosion-causing environment rather than directly establishing the actual corrosion rate of culverts.

On the other hand there is no doubt that the frequency or continuity of the water flow directly affects the rate of corrosion. While the direct relationship is not known, it is expected that continued accumulation of data will disclose the relative influence of the average annual rainfall on the rate of corrosion of culverts when other factors are equal.

It also appears that the condition of the environment, i.e., as indicated by the pH and the corrosive salts in a soil, is a reflection of the over-all average rainfall.

X. THE ELECTRICAL RESISTIVITY OF SOILS

It has been well established that the electrical conductivity of an electrolyte has a great influence on the rate of corrosion. For instance, an electrolyte with a low electrical resistance will allow corrosion to proceed at a greater rate under the same conditions than one with a high electrical resistance. This is because corrosion is an electro-chemical phenomenon. The greater the electrical current flow, the greater the loss of metal.

Electrical resistance of miscellaneous materials is generally expressed in ohms per cubic centimeter. For example, sea water has an electrical resistivity of approximately 50 ohms per cubic centimeter. Alkali soils may range between 10 and 200 ohms cm^3, while a clean sand may measure greater than 10,000 ohm cm^3.

As shown by the National Bureau of Standards in Circular 579, the measured electrical resistance of soils varies with compaction, soluble salts, moisture content and temperature.

The variations in the electrical resistivity with moisture content of an Ottawa sand, a beach sand, clay and peat are shown on Exhibit IV. Because of the variations in the resistivity of soils with moisture, the comparisons of the electrical resistivity measurements would have to represent the same condition for all soils. For this reason, all of the reported electrical resistivity measurements are at the moisture content that produced the minimum values.

As the minimum resistivity is usually obtained when the soil is saturated to the point of forming a slurry, the factor of compaction is a relatively minor item and is therefore eliminated as a variable. Also, as the measurement of soil resistivity is made in the laboratory, any error due to temperature variation should be sufficiently small to be neglected.

XI. THE INFLUENCE OF SOIL RESISTIVITY

Using the data obtained from the observed corrosion rate of culverts in areas where the soil pH was between 8.0 and 8.5 and the annual rainfall was less than 5 inches per year, Exhibit V was plotted to determine whether there was a relationship between soil resistivity and the corrosion rate of culverts. In Exhibit V, the trend of the data indicated that the apparent life of metal culverts would increase with an increase in the resistivity of the soil.

The data shown in Exhibit V suggests that a metal culvert in contact with soil of a low resistivity will have a short service life while a culvert that is in an environment of high electrical resistivity will have a longer service life. This same general correlation for underground pipe lines has been found by other investigators, and is summarized in detail in the National Bureau of Standards Circular 579.

Since the factors of annual rainfall and soil pH apparently did not correlate directly with the anticipated trend of service life of metal pipes, rainfall and soil pH were plotted against soil resistivity to determine the reason for the apparent lack of correlation.

The plot of the soil resistivity against annual rainfall shown on Exhibit VI indicates that as the average rainfall increases, so does the electrical resistivity of the soil. As the resistivity of the soil is greatly influenced by the quantity of dissolved solids or soluble salts, this plot confirms other evidence that rainfall is a predominant factor in the leaching out of the soluble salts in a soil.

As a further check on the evidence that the rainfall modifies the environment by leaching action, the electrical resistivity was plotted against the pH of the soil, as shown on Exhibit VII. Exhibit VII indicates that as the pH of the soil increases, the electrical resistivity decreases. Normally, the soils of high pH are found in the arid desert regions.

As an additional observation on the influence of the electrical resistivity of and the sulphate (SO_4) content of the soils, the data from this culvert survey and that published by the National Bureau of Standards were compared. It was found that in the plot of about 250 soils throughout the United States there was a trend in the data which indicated that as the resistivity of the soil decreased, the sulphate content also increased. None of these soils having a sulphate content exceeding 2000 parts per million had a minimum electrical resistance greater than 2000 ohm cm^3.

XII. CONCRETE CULVERTS

While this study was not aimed at determining the probable life of concrete materials, observations of existing structures seemed to bear out the findings of others.

In areas of low pH (acidic), evidences of cement leaching out of the culvert inverts was noted. In watersheds containing sulphates, spalling and other deterioration was noted. In sea water environments, rusting of reinforcing steel and consequent spalling of the concrete was noted.

The above factors have been thoroughly studied and reported by others so no detailed work was considered necessary in this study.

Insofar as California is concerned, it is usually necessary to make special designs to take care of acidic or salt water conditions. Type II Portland cement is used for all highway structures and has been shown to be resistant to moderate sulphate attack. However, occasionally such sulphates reach a high enough magnitude to require Type V cement. For this reason it is desirable to make a sulphate determination of the watershed channel at a proposed culvert site.

Two types of aggressive waters may affect concrete used in highway construction. These are acid waters and sulphate bearing waters.

Moderate acidity in natural waters is not uncommon. A few cases of acidity strong enough to attack concrete have been found in California. For the usual concrete pipe no concern need be felt if the pH value of the water is higher than 5.5. Small drain pipe having a shell thickness of 1 inch or less may be harmfully affected if the pH is less than 6.5 and this also applies to porous pipe of any shell thickness.

Indications of acidity greater than these limiting values should be checked thoroughly by tests made at the site. If the acidity is confirmed, the results and a sample should be referred to Headquarters Materials and Research Department for final recommendations and additional analysis.

Sulphates attack concrete by chemically forming new compounds which exert sufficient pressure to disrupt the concrete. Sulphates are found in sea water and are also present in most of the so-called "alkali" soils and waters.

Type II cement, as required in our Standard Specifications, has been found to be resistant to attack by sea water if the concrete is of good quality and contains a minimum of 6 sacks of cement per cubic yard. Therefore, it can be concluded that

our Standard Specifications provide Class A concrete (requiring
Type II cement) that will be adequately resistant against sulphates
found in inland waters where the SO₄ content does not exceed about
2000 parts per million.

This study did not determine the relationship between
the resistivity and the sulphate content of waters; however, it did
determine this relationship for soils. Therefore, it is recommended
that all water samples that measure less than 3000 ohm/cm³ be sub-
mitted to the Materials and Research Department for analysis and
recommendation for prevention of concrete deterioration. If the
waters are found to have greater than 3000 ohm/cm³, then it may be
considered that aggressive quantities of sulphates are not present.

Soils may attack concrete because of their content of
water soluble sulphates. The action must take place through the
medium of water. One assumption must be made as to the propor-
tions of soil and water since this proportion will affect the con-
centration of sulphates in the water. It is assumed that wet soil
may contain soil and water in the proportions of 2 to 1 by weight.
Therefore, a soil containing more than 1000 ppm (or 0.1 per unit
by weight) of SO₄ could yield water containing 2000 ppm of SO₄.

In the course of making resistivity tests of soil, water
is added in amounts ranging from about 25 percent moisture content
upward. If the soil at any tested water content has a measured
resistivity of less than 3000 ohm/cm, then it is suspected to
contain sulphates in amounts harmful to concrete. In such cases
samples should be submitted to the Headquarters Materials and
Research Department for analysis and recommendation. If, on the
other hand, the resistivity of the soil is found to exceed 3000
ohm/cm at all tested water contents, the results indicate a con-
centration of SO₄ not likely to attack concrete containing Type II
cement. In this case a sample need not be submitted to the Head-
quarters Materials and Research Department for further analysis.

There are several ways of increasing the resistance of
concrete to sulphate attack. Among these are air-entrainment,
richer mixes, and the use of Type V cement. Well-made centrifugal
or machine-tamped pipe usually has a density sufficient to render
it resistant to fairly high sulphate concentrations. Cast-in-
place box culverts on the other hand are less "safe" from sul-
phate attack.

The presence of salts other than sulphates in water or
soils may cause corrosion of the reinforcement in concrete. This
is particularly the case in large structures where differences
in moisture content from one mass of concrete to another are likely
to prevail. The probability of corrosion of reinforcement in
concrete pipes is not great, because of dense concrete and little
difference in moisture content from point to point in the shell
when the pipe is placed in the normal manner. However, if concrete
pipe is to be used in direct contact with salt or tidal water, the
site and details of construction should be reviewed so as to deter-
mine the feasibility of using standard concrete pipe in this type
of environment.

EXHIBIT I

CALIFORNIA DIVISION OF HIGHWAYS
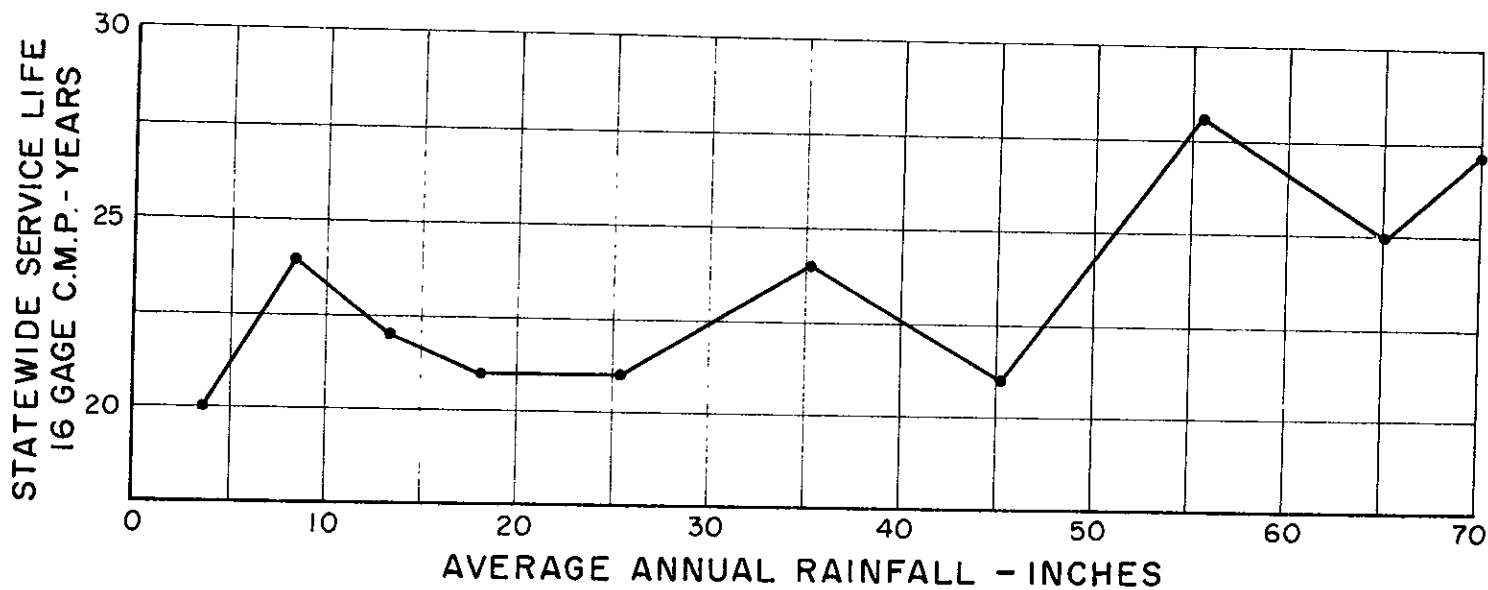**MATERIALS & RESEARCH DEPARTMENT**

CHART FOR ESTIMATING
METAL CULVERT CORROSION RATE

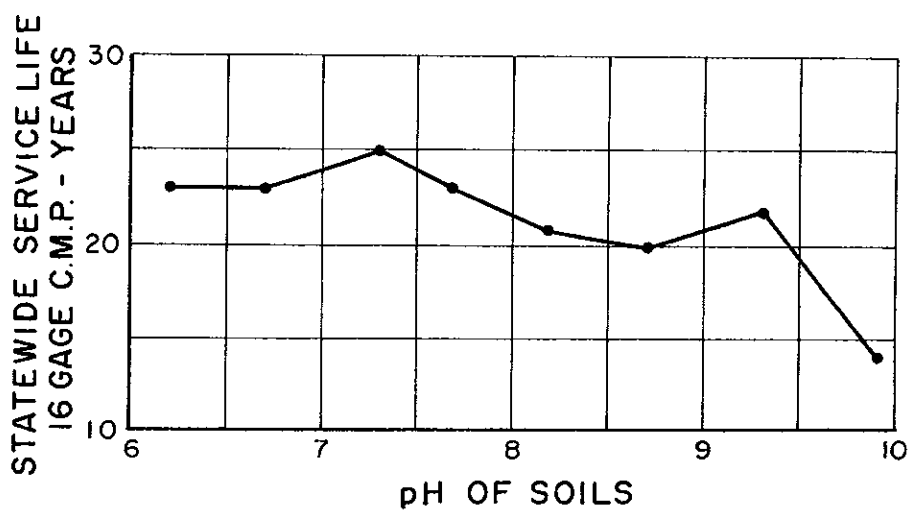YEARS TO PERFORATION - 16 GAGE METAL CULVERT
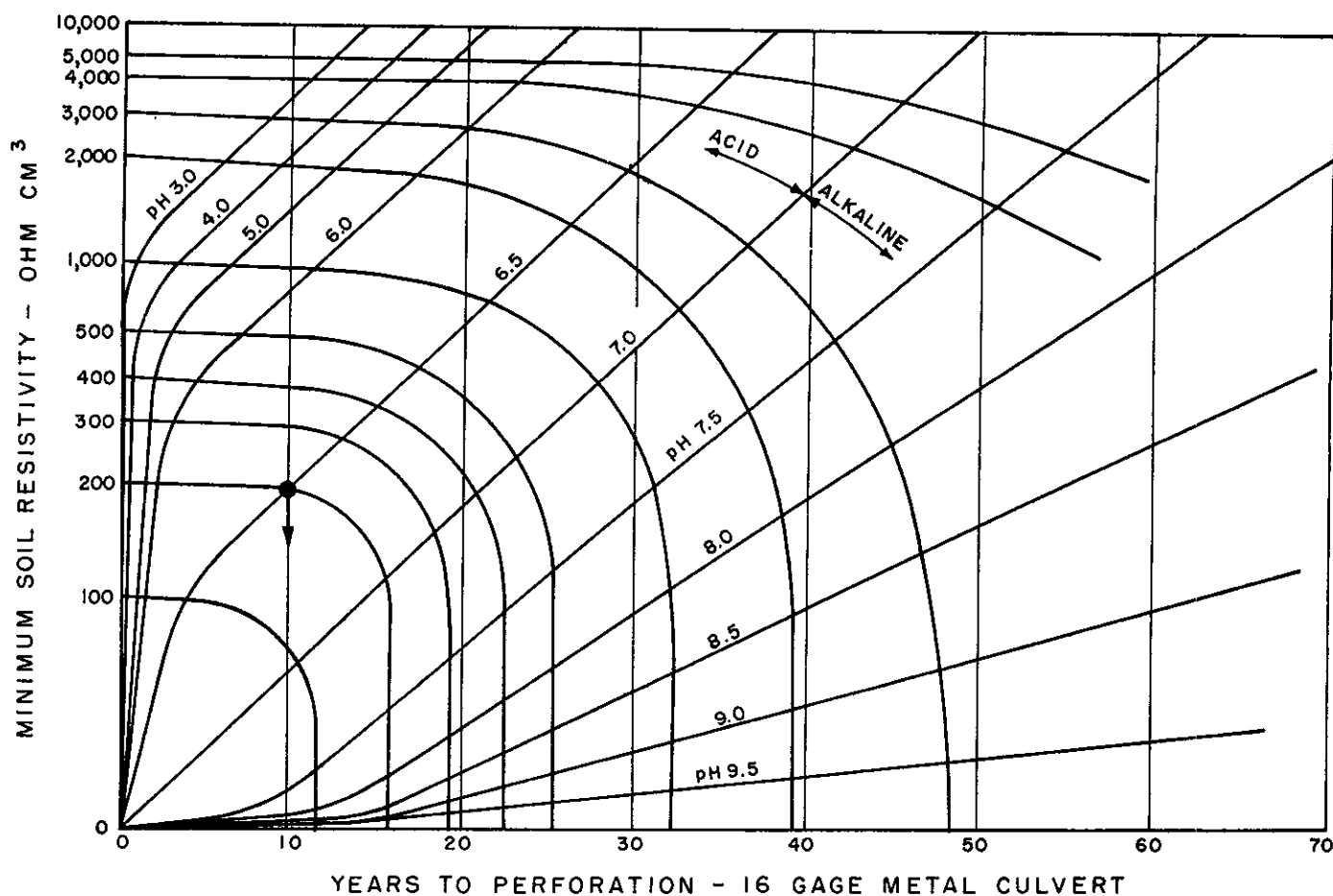
EXAMPLE: Given, pH = 6.5 & Resistivity = 200 ohm cm^3
Then 16 gage CMP perforated in 10 years.
For a culvert metal gage of 12 multiply
years by factor below. i.e. 1.8 x 10 = 18 years

Gage	14	12	10	8	6	2	0	000
Factor	1.3	1.8	2.3	2.8	3.3	4.3	5.0	6.0

EXHIBIT II

AVERAGE ANNUAL RAINFALL
AGAINST LIFE OF C.M.P.

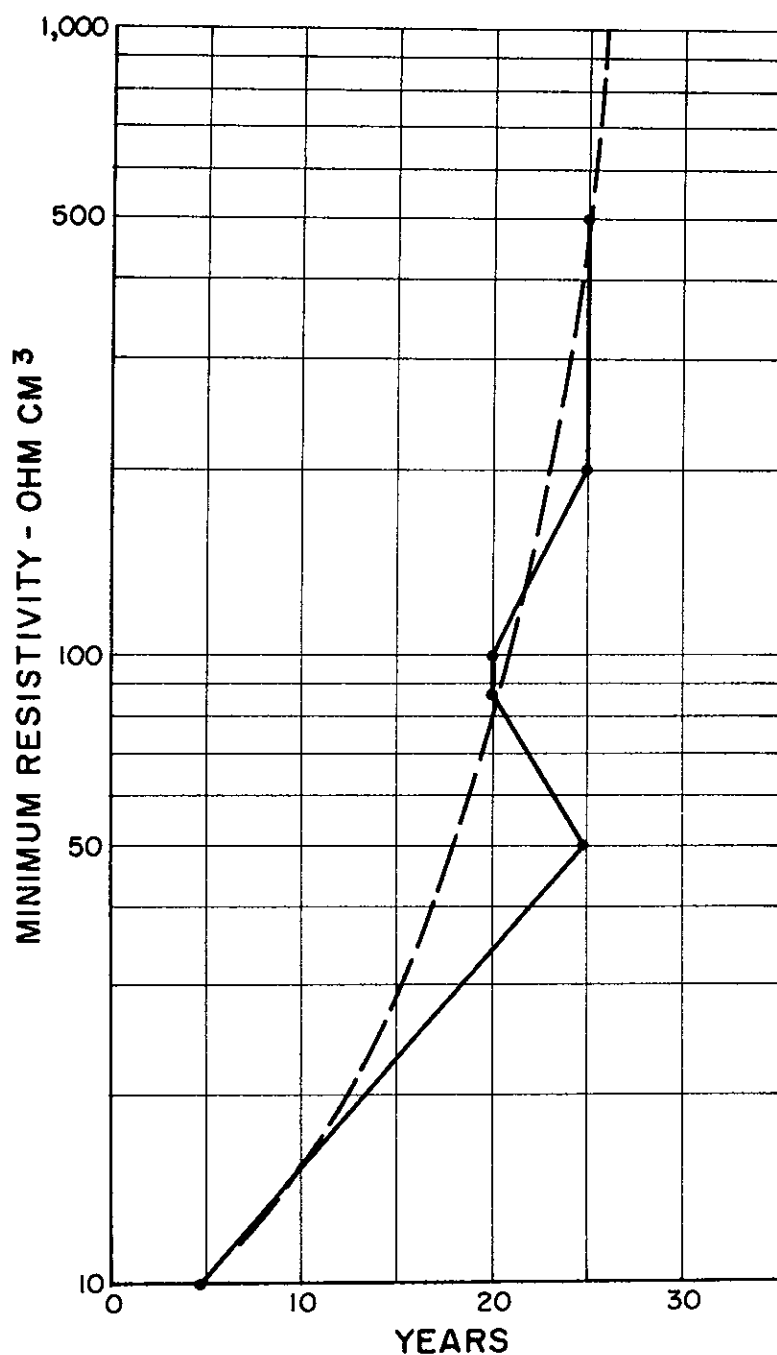

pH AGAINST
LIFE OF C.M.P.

EXHIBIT III
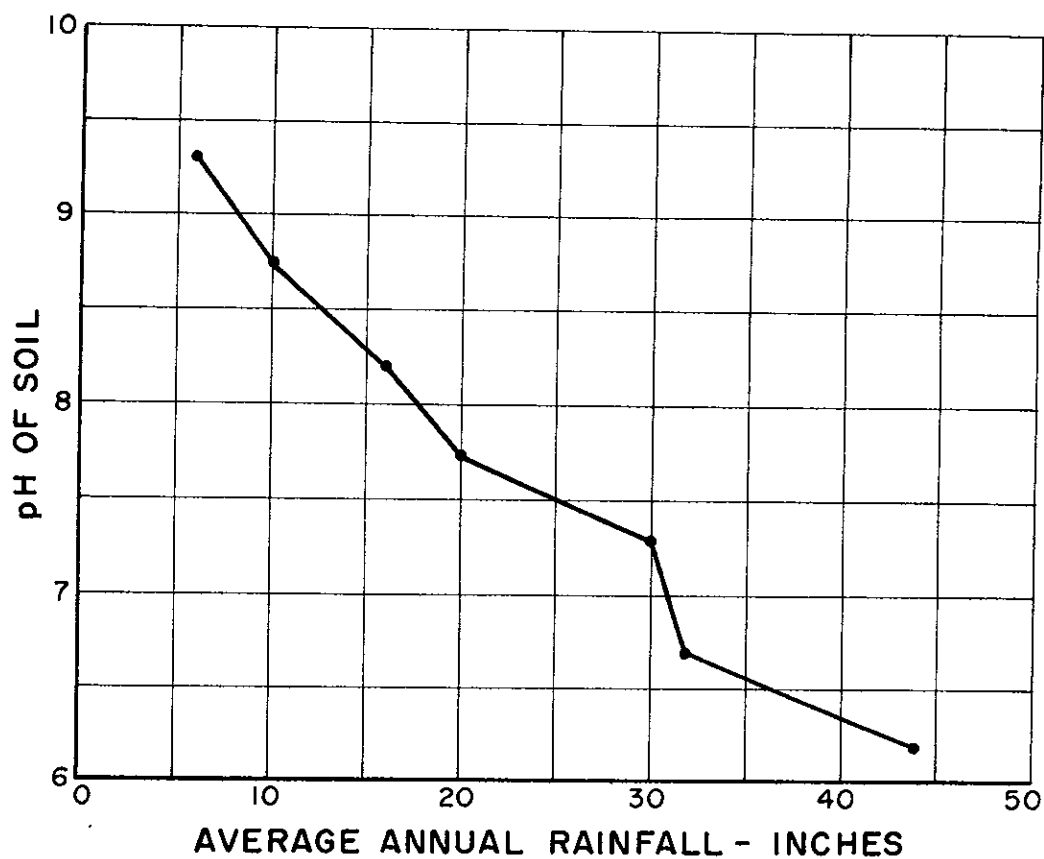
pH AGAINST
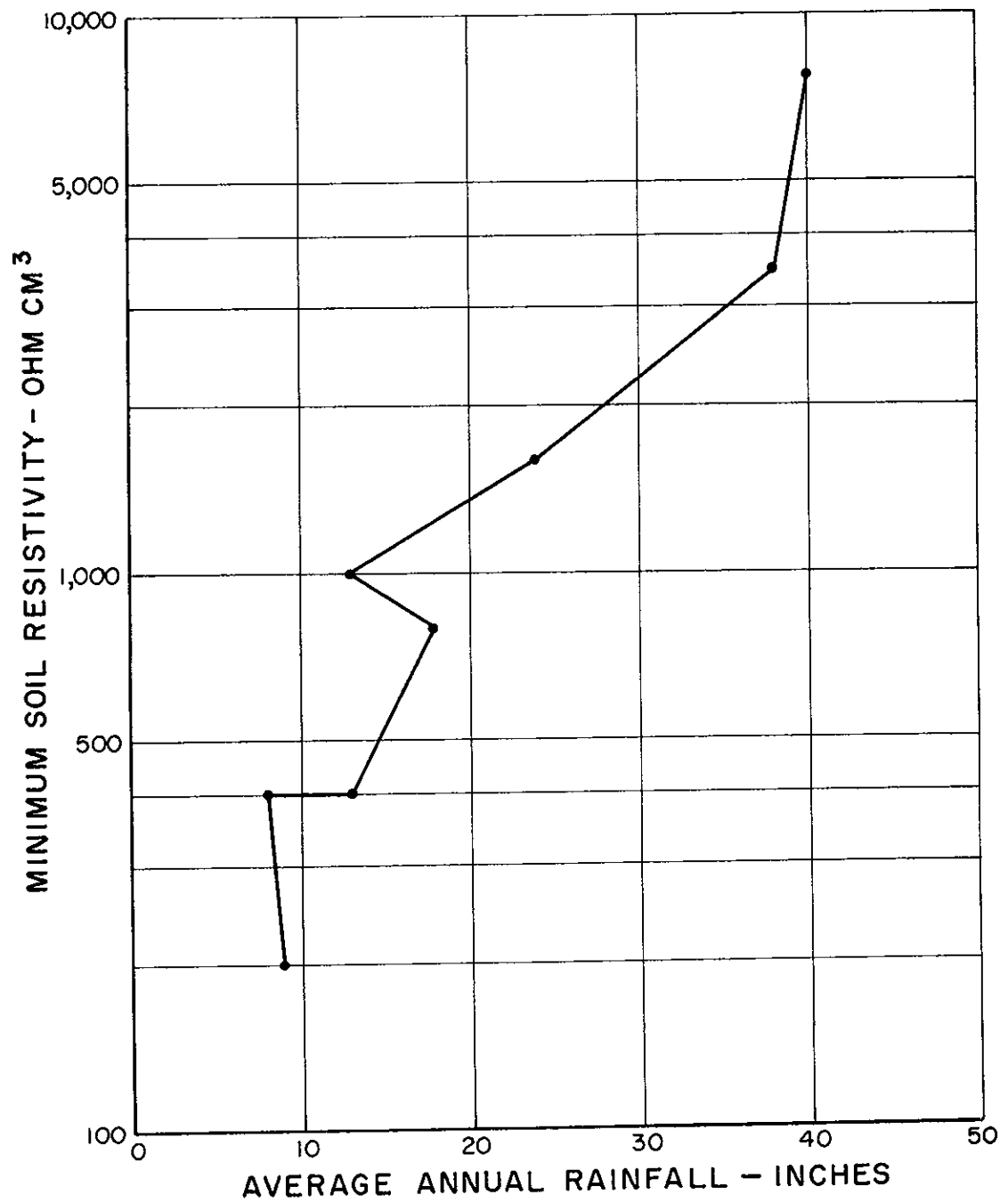AVERAGE ANNUAL RAINFALL

EXHIBIT IV
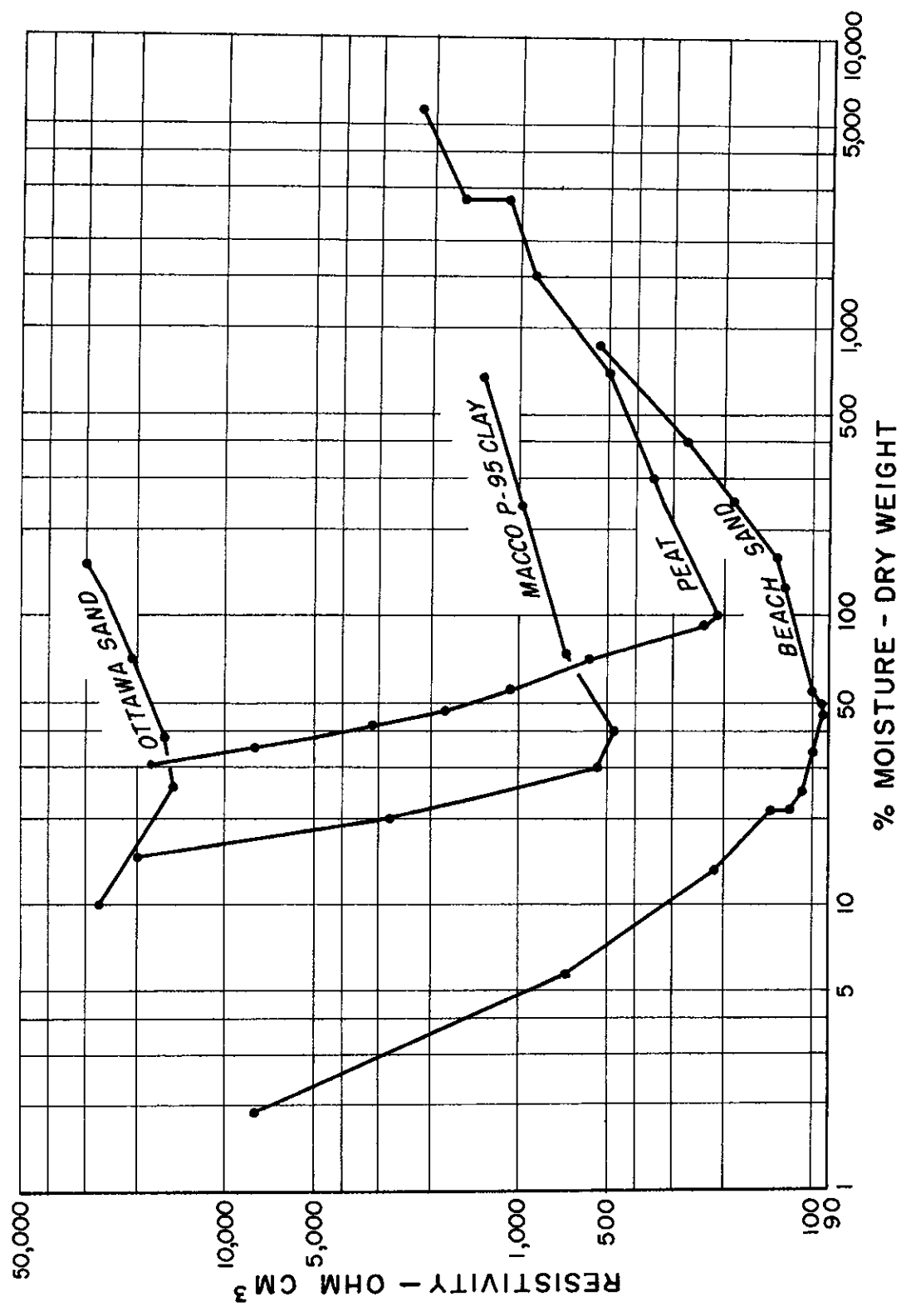
MOISTURE CONTENT AGAINST
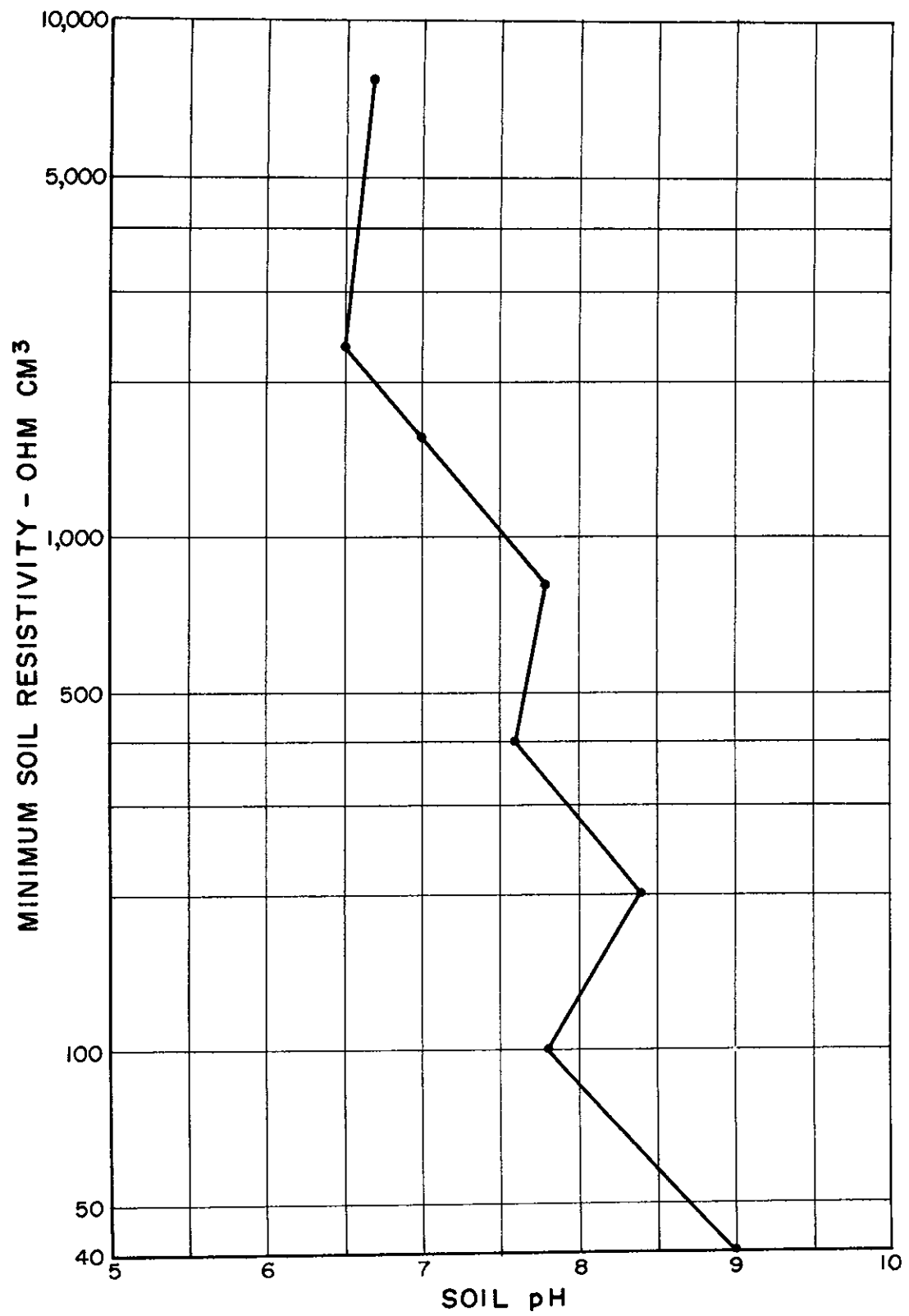RESISTIVITY OF SOILS

EXHIBIT V

Note: So as to maintain
but one variable pH
was limited between
8.0 & 8.5. Annual
rainfall was limited
to less than 5" per yr.

RESISTIVITY AGAINST SERVICE LIFE
OF 16 GAGE C.M.P.

EXHIBIT VI

SOIL RESISTIVITY AGAINST
AVERAGE ANNUAL RAINFALL

EXHIBIT VII

SOIL RESISTIVITY
AGAINST pH